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Selective Cone-Beam CT Referral for Mandibular Third Molars Based on Panoramic Risk Signs: A Retrospective Cross-Sectional Diagnostic Study

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Abstract

Background/Objectives: Panoramic radiography is the first-line examination before mandibular third molar extraction, but two-dimensional imaging may limit assessment of root proximity to the inferior alveolar canal. This study assessed panoramic risk signs for identifying root–inferior alveolar canal (IAC) contact, using cone-beam computed tomography (CBCT) as the reference standard, and evaluated a selective CBCT referral approach. **Methods**: This retrospective cross-sectional diagnostic study included 86 mandibular third molars from 62 patients. Four examiners with different clinical experience independently assessed panoramic radiographs for established risk signs. CBCT confirmed root–IAC contact and measured the minimum root–IAC distance. Interobserver agreement, regression analyses, ROC-based diagnostic performance, and an exploratory selective CBCT referral framework were assessed. **Results**: Root darkening and cortical interruption were the most frequent signs. Interobserver agreement for panoramic signs was generally low, although higher between the most experienced examiners. CBCT measurement reliability was moderate for vertical canal dimensions and root–IAC distance, but poor for transverse canal dimensions. Cortical interruption was the only sign significantly associated with CBCT-confirmed root–IAC contact. Panoramic radiography underestimated the root–IAC distance. The selective framework would have recommended CBCT in 33/86 molars (38.4%) and identified 33/38 confirmed contacts (86.8%). **Conclusions**: Cortical interruption appears to be the most clinically relevant panoramic sign for identifying mandibular third molars that may benefit from additional three-dimensional anatomical assessment. Structured criteria and senior review in borderline cases may support radiation justification and avoid routine CBCT use.

Keywords: third molar; cone-beam computed tomography; panoramic radiography; inferior alveolar canal; diagnostic accuracy; dental imaging

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1. Introduction

The extraction of mandibular third molars is one of the most common procedures in oral and maxillofacial surgery and carries a potential risk of inferior alveolar nerve (IAN) injury, with reported incidences reaching up to 8.4% in the literature [1–3]. Proper surgical planning requires an accurate assessment of the anatomical relationship between the roots and the inferior alveolar canal (IAC) in order to minimise the risk of complications.

Panoramic radiography (OPG) is typically the initial imaging technique due to its wide availability, low cost, and reduced radiation dose [4,5]. However, being a two-dimensional modality, it may present distortions and superimpositions that hinder interpretation, particularly in cases where the roots lie close to the IAC [4–8]. Cone-beam computed tomography (CBCT) offers precise three-dimensional evaluation, but its indiscriminate use results in increased radiation exposure, unnecessary costs, and the risk of trivialising its indication [9–14].

However, the additional anatomical information provided by CBCT does not necessarily translate into changes in surgical management or into a reduction in postoperative inferior alveolar nerve sensory disturbance. A systematic review by Araujo et al. [15] reported that, compared with panoramic radiography, CBCT did not consistently influence the surgical technique used for mandibular third molar removal. Therefore, CBCT should not be considered a routine examination but rather a selectively indicated imaging modality when the expected diagnostic benefit may influence preoperative planning.

Recent studies have further emphasised that CBCT should not be considered only in terms of whether it is indicated but also in terms of how image acquisition is optimised once three-dimensional imaging is justified. In particular, recent low-dose CBCT studies in mandibular third molar assessment suggest that diagnostically acceptable information may be obtained with reduced-dose protocols in selected cases, supporting a contemporary approach based on justification and optimisation rather than routine high-resolution imaging [16,17].

In many clinical settings, access to CBCT has increased substantially, including in general dental practices. This broader availability facilitates immediate imaging decisions at the point of care but may also contribute to variability in prescription patterns and potential overuse when clear and standardised criteria are lacking. Consequently, selective CBCT referral strategies should be applicable to routine preoperative clinical settings, where imaging decisions are often made by clinicians with different levels of experience. This is particularly relevant because recent evidence suggests that the impact of CBCT on treatment decisions may differ according to clinicians' level of experience [18].

Therefore, this study assessed the performance of a pragmatic, guideline-informed selective CBCT referral framework and examined how examiner experience affects its applicability.

Although the predictive value of panoramic signs has been widely investigated, several clinically relevant issues remain unresolved. First, panoramic signs are interpreted by clinicians with different levels of experience, and their reproducibility may influence CBCT referral decisions in routine clinical practice. Second, CBCT-confirmed root–IAC contact should be clearly distinguished from postoperative inferior alveolar nerve sensory disturbance. Root–IAC contact represents an anatomical imaging finding that may assist anatomical clarification and surgical planning in selected cases, but it should not be considered a direct surrogate for nerve injury. Third, current evidence indicates that CBCT findings do not necessarily change surgical treatment or reduce postoperative neurosensory complications when CBCT is used indiscriminately. Therefore, the present study does not propose root–IAC contact as a predictor of postoperative nerve injury. Rather, it evaluates the association between panoramic signs and a clearly defined anatomical CBCT finding, together with examiner agreement and an exploratory selective CBCT referral framework for radiological decision-making.

Root–IAC contact was chosen as the reference imaging outcome because it represents a clearly defined anatomical finding assessable on CBCT and directly related to the radiological question of whether panoramic signs correspond to true three-dimensional proximity. However, this endpoint should not be interpreted as a clinical outcome or as a validated

predictor of postoperative sensory disturbance. The clinically relevant endpoint remains postoperative inferior alveolar nerve dysfunction, which was not systematically assessed in the present retrospective study.

The aim of this study was to evaluate the association between panoramic risk signs and CBCT-confirmed root–IAC contact, to assess interobserver agreement according to examiner experience, and to explore a selective CBCT referral framework for anatomical radiological assessment of mandibular third molars. The study was not designed to predict postoperative inferior alveolar nerve sensory disturbance.

2. Materials and Methods

This retrospective cross-sectional diagnostic study was conducted in a university-based oral surgery setting and reported in accordance with the STARD guidelines. The study protocol was approved by the Biomedical Research Ethics Committee of Universidad CEU Cardenal Herrera (protocol code CEEI23/432; date of approval: 15 November 2023), and all participants signed informed consent in accordance with the Declaration of Helsinki. Radiographic records obtained between 2021 and 2025 were retrospectively reviewed.

2.1. Selection Criteria

Patients aged 18 to 90 years were included if they presented mandibular third molars with complete root formation and had both preoperative panoramic radiography (OPG) and cone-beam computed tomography (CBCT) available.

Exclusion criteria were low-quality imaging; local alterations preventing accurate interpretation (cysts, periapical lesions, mandibular fractures, or osteosynthesis hardware); pregnancy; history of head and neck radiotherapy; ongoing oncologic treatment; or refusal to undergo radiographic studies.

2.2. Sample Size and Unit of Analysis

Sample size was calculated at the tooth level, because the primary outcome of the study was CBCT-confirmed root–IAC contact for each mandibular third molar. Assuming a 95% confidence level, a conservative expected proportion of 50% to maximise sample size requirements, and an accepted precision of approximately ±11%, a minimum sample of 80 mandibular third molars was required. The sample-size calculation was based on the primary outcome and was not intended to power all secondary regression, ROC, or diagnostic accuracy analyses, which should therefore be interpreted as exploratory.

The final sample included 62 patients and 86 mandibular third molars, therefore exceeding the minimum estimated sample size. Each mandibular third molar was independently assessed by four examiners, generating 344 individual radiographic evaluations. Diagnostic accuracy analyses, regression models, ROC curve analysis, and retrospective application of the selective CBCT referral framework were performed at the tooth level.

Interobserver agreement analyses were based on the individual examiner assessments of each tooth. When both mandibular third molars from the same patient were included, they were analysed as separate anatomical units because each tooth had an independent spatial relationship with the IAC. The potential non-independence of bilateral molars from the same patient was considered when interpreting the findings and is acknowledged as a limitation.

Four examiners with different levels of clinical experience assessed the panoramic radiographs: a first-year postgraduate student, a second-year postgraduate student, a third-year postgraduate student, and a faculty oral surgeon with more than 10 years of clinical experience. Each examiner recorded the presence or absence of the radiographic signs described by Rood and Shehab [1], including cortical interruption, root darkening,

curved or deflected roots, root narrowing, canal deviation or narrowing, bifid apices, and "island-shaped" apices (Figure 1). To reduce measurement bias, all panoramic radiographs were independently assessed using predefined radiographic criteria.

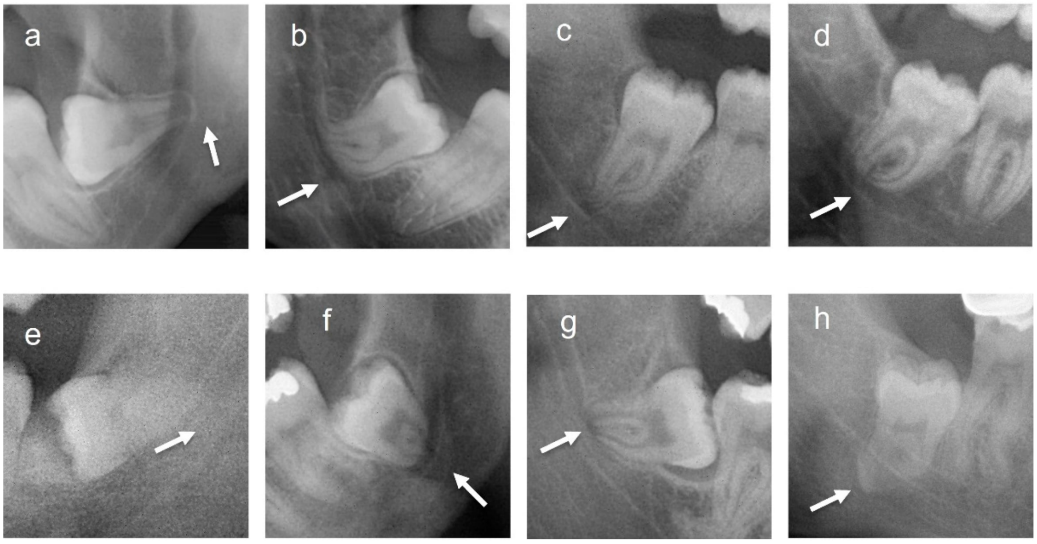


Figure 1. Representative panoramic radiographic risk signs assessed in the study: (**a**) Root darkening. (**b**) Interruption of the superior cortical outline of the mandibular canal. (**c**) Canal narrowing. (**d**) Canal deviation. (**e**) Root narrowing. (**f**) Root deflection. (**g**) Bifid apex. (**h**) Island-shaped apex. Arrows indicate the apical root region of the mandibular third molar where the radiographic feature of interest is observed.

For the tooth-level regression analyses and retrospective application of the selective CBCT referral framework, the panoramic assessment performed by the most experienced examiner was used as the primary index-test assessment. This examiner was a faculty oral surgeon with more than 10 years of clinical experience and served as the reference panoramic examiner. Interobserver agreement analyses were performed separately to evaluate the reproducibility of panoramic sign identification across examiners with different levels of clinical experience.

CBCT imaging Planmeca ProMax 3D Classic® (Planmeca Oy, Helsinki, Finland) was used as the reference standard to confirm root–IAC contact and to measure the minimum distance, in millimetres, between the root and the IAC. The same four examiners who assessed the panoramic radiographs also independently evaluated the CBCT examinations using the full CBCT volume and multiplanar reconstruction views. Root–IAC contact was defined as the absence of visible bony separation between the mandibular third molar root and the cortical boundary of the IAC on at least one CBCT plane. The minimum root–IAC distance was measured at the point of closest proximity between the root surface and the IAC, using axial, coronal, and sagittal views to identify the region of closest proximity. For the primary tooth-level analyses, the CBCT assessment performed by the most experienced examiner was used as the reference anatomical assessment. The same four examiners independently performed CBCT measurements using multiplanar reconstructions. Interobserver reliability was assessed for three continuous CBCT variables: the vertical and transverse dimensions of the inferior alveolar canal and the minimum root–IAC distance, all expressed in millimetres. Agreement was evaluated using intraclass correlation coefficients (ICCs) with 95% confidence intervals.

Panoramic root–IAC distance was measured in millimetres (mm) on digital panoramic radiographs using the measurement tool of the imaging software. The distance was measured between the closest visible point of the mandibular third molar root and the superior

cortical outline of the mandibular canal. Because the study was retrospective and panoramic radiography is affected by magnification, projection geometry, and superimposition, no additional patient-specific magnification correction could be applied. Therefore, these measurements were interpreted as approximate two-dimensional estimates rather than true anatomical distances. The comparison with CBCT measurements was therefore considered exploratory. All examiners used predefined radiographic criteria for sign identification. However, no formal calibration session or intraobserver reproducibility assessment was performed before the reading session. This limitation was considered when interpreting the interobserver agreement results. Panoramic radiographs and CBCT images were visualized and assessed using Planmeca Romexis software (version 5.3.4.39; Planmeca Oy, Helsinki, Finland). Radiographic measurements were performed using the software's measurement tools.

2.3. Statistical Analysis

Statistical significance was set at $p < 0.05$. Numerical variables were described using the mean and standard deviation or the median and interquartile range (Q1–Q3), according to their distribution.

Interobserver agreement was assessed separately for panoramic radiographic signs and CBCT measurements. Cohen's kappa coefficients with 95% confidence intervals were calculated for the categorical panoramic signs. For continuous CBCT measurements, interobserver reliability was evaluated using intraclass correlation coefficients (ICCs) with 95% confidence intervals. The CBCT variables included the vertical and transverse dimensions of the inferior alveolar canal and the minimum root–IAC distance. To analyse the association between radiographic signs and root–IAC contact, a two-stage modelling approach was applied:

- Logistic regression to estimate the probability of root–IAC contact.
- Linear regression was used to assess the relationship between radiographic findings and root–IAC distance among mandibular third molars without CBCT-confirmed contact.

The optimal cutoff for the number of panoramic signs predicting complete root–IAC contact was determined using Youden's index. Diagnostic performance was evaluated through sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and ROC curve analysis. Internal validation with 1000 bootstrap resamples was performed to estimate optimism-corrected performance metrics.

The association between root position relative to the IAC and the radiographic signs was examined using independent logistic regression models.

Data processing and statistical analyses were performed using R software version 4.3.2 [19].

For the retrospective analysis, CBCT indication was operationally defined as the presence of cortical interruption or two or more panoramic risk signs. Examiner experience and medico-legal considerations were incorporated as clinical modifiers in the proposed framework, but not as additional numerical criteria for the retrospective diagnostic performance analysis.

Patient-level random-effects models were explored to account for possible within-patient correlation; however, given the limited sample size and the structure of the dataset, these models showed convergence problems and did not provide stable estimates suitable for reporting. Therefore, the prespecified tooth-level analysis was retained and interpreted as exploratory.

3. Results

3.1. Sample Characteristics and Imaging Findings

The characteristics of the study sample, imaging assessments, examiner profile, and main CBCT findings are summarised in Table 1.

Table 1. Sample characteristics, imaging assessment, and main radiographic findings.

Variable	Value
Patients, *n*	62
Mandibular third molars, *n*	86
Individual radiographic evaluations, *n*	344
Age, years, mean ± SD	32.2 ± 13.4
Male patients, *n* (%)	29 (46.8)
Female patients, *n* (%)	33 (53.2)
Imaging modalities available	OPG and CBCT
Reference standard	CBCT-confirmed root–IAC contact
Number of examiners	4
Examiner 1	First-year postgraduate student
Examiner 2	Second-year postgraduate student
Examiner 3	Third-year postgraduate student
Examiner 4	Faculty oral surgeon, >10 years' experience
Most frequent panoramic signs	Root darkening and cortical interruption
Root darkening, %	37.5
Cortical interruption, %	30.6
Curved or deflected roots, %	18–21
Root narrowing, canal narrowing and canal deviation	<10% each
Bifid apices/island-shaped apices	Anecdotal findings
CBCT-confirmed root–IAC contact, *n* (%)	38 (44.2)
No CBCT-confirmed root–IAC contact, *n* (%)	48 (55.8)

OPG, panoramic radiography; CBCT, cone-beam computed tomography; SD, standard deviation.

3.2. Distribution of Radiographic Signs

Among the 86 mandibular third molars evaluated, the most frequent radiographic signs on panoramic imaging were cortical interruption and root darkening (30.6% and 37.5%, respectively). Curved or deflected roots were observed in 18–21% of cases. Root narrowing, canal narrowing, and canal deviation were less common findings (<10%). Bifid apices and "island-shaped" apices were identified only anecdotally. These results are presented in Supplementary Figure S1.

3.3. Interobserver Agreement

Interobserver agreement for the identification of the different radiographic signs was generally low among most examiners, with kappa coefficients close to zero and wide confidence intervals.

The highest agreement was observed between Examiners 3 and 4, particularly for root darkening (κ [95% CI] = 0.64 [0.48–0.79]), curved or deflected roots (κ [95% CI] = 0.59

[0.39–0.80]), and root narrowing (κ [95% CI] = 0.64 [0.33–0.96]), showing moderate to substantial levels of agreement.

Interobserver agreement between the two most experienced examiners is shown in Table 2. The highest agreement was observed for root darkening, curved or deflected roots, and root narrowing, with κ values ranging from 0.59 to 0.64 in the total sample. Agreement was lower for interruption of the cortical outline, canal deviation, and canal narrowing. Kappa values could not be estimated for the island-shaped apex because this sign showed no variability between the two examiners.

Table 2. Interobserver agreement between Examiners 3 and 4 for panoramic radiographic signs.

Radiographic Sign	Total κ [95% CI]	Total Agreement, %	ORTO 3.8 κ [95% CI]	ORTO 3.8 Agreement, %	ORTO 4.8 κ [95% CI]	ORTO 4.8 Agreement, %
Root darkening	0.64 [0.48–0.79]	81.71	0.58 [0.35–0.81]	79.07	0.69 [0.48–0.91]	84.21
Curved or deflected roots	0.59 [0.39–0.80]	85.37	0.44 [0.15–0.74]	79.07	0.77 [0.53–1.00]	92.11
Root narrowing	0.64 [0.33–0.96]	95.12	0.64 [0.20–1.00]	95.35	0.00 [0.00–0.00]	100.00
Bifid apices over the canal	0.31 [−0.18–0.80]	95.12	0.64 [0.20–1.00]	95.35	Not estimable	100.00
Interruption of the cortical outline	0.35 [0.18–0.52]	67.07	0.29 [0.06–0.53]	62.79	0.40 [0.15–0.66]	71.05
Canal deviation	0.24 [0.01–0.46]	81.71	0.17 [−0.12–0.45]	81.40	0.30 [−0.03–0.64]	81.58
Canal narrowing	0.21 [0.01–0.42]	79.27	0.00 [0.00–0.00]	79.07	0.35 [0.04–0.65]	78.95
Island-shaped apex	Not estimable	100.00	Not estimable	100.00	Not estimable	100.00

κ, Cohen's kappa coefficient; CI, confidence interval. "Not estimable" indicates that κ could not be calculated because one or both examiners showed no variability in the classification of that sign.

Interobserver reliability was also evaluated for three continuous CBCT measurements. Moderate agreement was observed for the vertical dimension of the inferior alveolar canal (ICC = 0.60; 95% CI: 0.48–0.71) and the minimum root–IAC distance (ICC = 0.58; 95% CI: 0.46–0.70). In contrast, agreement for the transverse dimension of the inferior alveolar canal was poor (ICC = 0.28; 95% CI: 0.16–0.42). These findings indicate that the reproducibility of CBCT measurements varied according to the anatomical parameter assessed. These results are summarised in Table 3.

Table 3. Interobserver reliability of cone-beam computed tomography (CBCT) measurements among the four examiners.

CBCT Measurement	ICC	95% CI	Agreement
Vertical dimension of the inferior alveolar canal	0.60	0.48–0.71	Moderate
Transverse dimension of the inferior alveolar canal	0.28	0.16–0.42	Poor
Minimum root–inferior alveolar canal distance	0.58	0.46–0.70	Moderate

ICC, intraclass correlation coefficient; CI, confidence interval; CBCT, cone-beam computed tomography. All measurements were expressed in millimetres.

3.4. Association Between Radiographic Signs and Root–IAC Contact

Cortical interruption was the only sign significantly associated with the presence of root–IAC contact (OR = 3.46; 95% CI: 1.23–10.83).

In contrast, among mandibular third molars without root–IAC contact, cortical interruption was not associated with either greater or lesser distance to the canal (β [95% CI] = 0.10 [−0.78 to 0.99]; $p = 0.816$). The optimal cutoff for predicting complete root–IAC contact based on the number of radiographic signs was the presence of at least one sign. CBCT-confirmed root–IAC contact was more frequent among mandibular third molars presenting at least one panoramic risk sign than among those without radiographic signs. Diagnostic accuracy estimates were calculated using CBCT-confirmed contact as the reference standard. Figure 2 displays the ROC curve assessing the discriminative ability of the number of panoramic risk signs to identify CBCT-confirmed root–IAC contact. The optimal cutoff, determined using Youden's index, was the presence of at least one panoramic risk sign. At this cutoff, the optimism-corrected estimates were as follows: sensitivity, 0.86; specificity, 0.41; positive predictive value (PPV), 0.58; and negative predictive value (NPV), 0.78. Figure 3 illustrates the relationship between the cumulative number of panoramic signs and CBCT-confirmed root–IAC contact or distance. Although the presence of at least one sign maximised sensitivity according to Youden's index, the final selective referral framework prioritised clinical applicability by combining the strongest individual predictor, cortical interruption, with the presence of multiple radiographic signs.

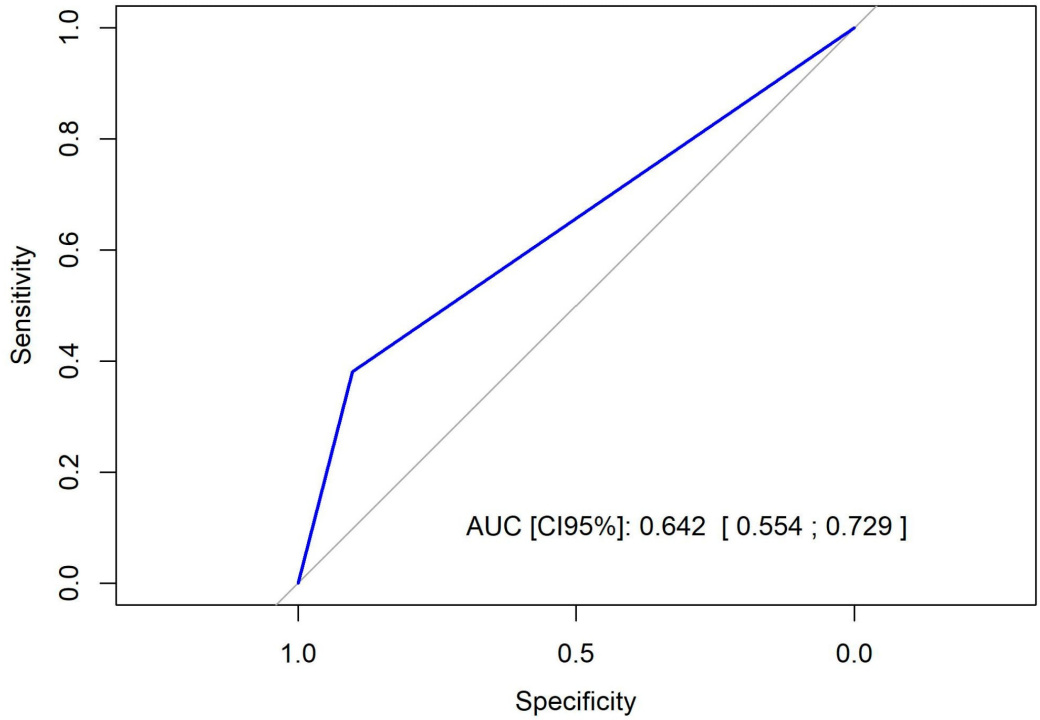


Figure 2. ROC curve assessing the discriminative ability of the combined count of panoramic signs to predict root–IAC contact confirmed by CBCT.

3.5. Comparison Between OPG and CBCT

The distances measured between the root and the IAC were significantly greater on CBCT than on OPG ($p < 0.001$), with a moderate effect size (Cohen's d = 0.72). The intraclass correlation coefficient indicated moderate agreement between the two methods (ICC = 0.66). Bland–Altman analysis revealed a systematic tendency for OPG to underestimate the root–IAC distance compared with CBCT.

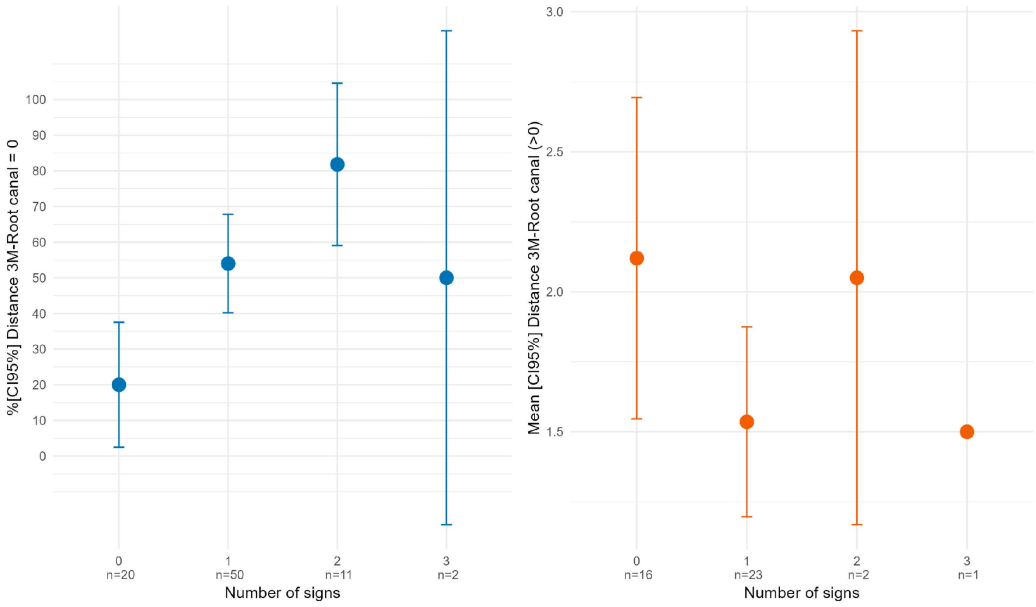


Figure 3. Relationship between the cumulative number of panoramic radiographic signs and CBCT findings. The number of observations contributing to each category of cumulative panoramic signs is shown in the figure.

3.6. Root Position Relative to the IAC

Logistic regression analysis identified curved or deflected roots as the only radiographic feature significantly associated with IAC position. The presence of this sign was associated with an 83% reduction in the odds of a lingual IAC location compared with molars without root curvature. These results are presented in Supplementary Figure S2.

3.7. Application of the Selective Framework

The retrospective application of the selective CBCT referral framework would have recommended CBCT in 33/86 mandibular third molars (38.4%). Among the 38 molars with CBCT-confirmed root–IAC contact, 33 fulfilled the framework criteria, whereas five contacts would not have been identified by the framework. By definition, these missed contacts corresponded to molars without cortical interruption and with fewer than two panoramic risk signs. No molars without CBCT-confirmed root–IAC contact fulfilled the framework criteria. Accordingly, the framework showed a sensitivity of 86.8%, specificity of 100.0%, PPV of 100.0%, and NPV of 90.6%. These findings should be interpreted as an internal retrospective performance estimate rather than external validation of the framework. The diagnostic performance of the selective CBCT referral framework is shown in Table 4. The decision framework is shown in Figure 4.

Table 4. Diagnostic performance of the selective CBCT referral framework.

Selective CBCT Framework	CBCT-Confirmed Root–IAC Contact	No CBCT-Confirmed Root–IAC Contact	Total
CBCT indicated	33	0	33
CBCT not indicated	5	48	53
Total	38	48	86

Sensitivity: 86.8% (95% CI: 72.7–94.2); specificity: 100.0% (95% CI: 92.6–100.0); PPV: 100.0% (95% CI: 89.6–100.0); NPV: 90.6% (95% CI: 79.7–95.9).

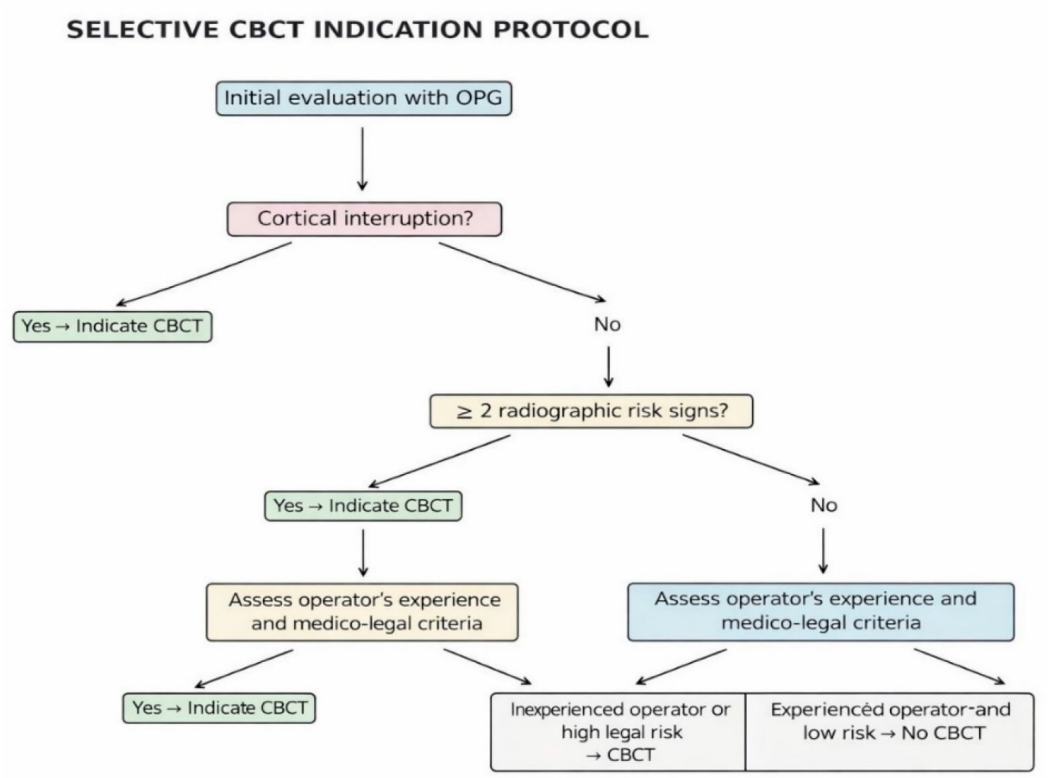


Figure 4. Proposed exploratory framework for selective CBCT referral in mandibular third molars.

4. Discussion

This study evaluated the association between panoramic radiographic signs and CBCT-confirmed root–IAC contact and assessed interobserver agreement in the interpretation of these signs. Root–IAC contact was used as an anatomical imaging endpoint, not as a surrogate for postoperative inferior alveolar nerve sensory disturbance.

Our results show that cortical interruption was the only panoramic sign significantly associated with CBCT-confirmed root–IAC contact, supporting its diagnostic relevance. However, interobserver agreement varied across signs and was generally higher among more experienced examiners. These findings are consistent with classic studies [1–3] as well as more recent investigations [4,5], which also identified this sign as a radiographic indicator of CBCT-confirmed anatomical root–IAC contact. In our analysis, the presence of two or more panoramic signs on OPG increased the probability of contact, reinforcing the usefulness of a combined radiographic assessment. Similar results have been reported in studies comparing the diagnostic performance of OPG and CBCT in evaluating root–IAC relationships [10–12].

The low kappa values observed among less experienced examiners should not be interpreted as an indication for routine CBCT in all cases. Rather, they reflect the limited reproducibility of subtle panoramic signs when interpreted by junior operators, a finding that may be partly influenced by the low prevalence of several signs and the prevalence-dependence of kappa statistics. Clinically, this supports the need for structured training, use of standardised visual criteria, and senior review in borderline cases before dismissing the need for CBCT.

The higher concordance observed was between Examiners 3 and 4, reflecting that interobserver agreement was influenced by the level of clinical experience. This finding highlights the importance of specialised training and the learning curve in radiographic interpretation, consistent with studies that have shown that diagnostic reliability depends on experience [5,6,17].

The assessment of interobserver reliability for CBCT measurements revealed moderate agreement for the minimum root–IAC distance and the vertical dimension of the inferior alveolar canal, whereas agreement for the transverse canal dimension was poor. These findings highlight that, despite the advantages of three-dimensional imaging, the reproducibility of anatomical CBCT measurements remains dependent on the parameter evaluated. Consequently, standardised measurement criteria and appropriate examiner training are important to improve the consistency of CBCT interpretation.

Regarding linear measurements, OPG systematically underestimated the root–IAC distance compared with CBCT. This pattern, previously reported [7,8], confirms that while OPG is useful as an initial examination, it has inherent limitations related to its two-dimensional nature. CBCT provides more precise three-dimensional anatomical information and may improve surgical planning in selected high-risk cases, although its routine use has not consistently been shown to reduce postoperative neurosensory complications [6,12,20–23]. The findings of the present study should be interpreted in the context of current evidence showing that CBCT-derived anatomical findings do not necessarily predict postoperative inferior alveolar nerve sensory disturbance or lead to changes in surgical management. Previous studies have suggested that absence of bony separation, canal position, canal compression, and other CBCT-related features may describe anatomical risk, but their validity as standalone predictors of postoperative sensory disturbance remains limited. Therefore, the selective referral framework proposed in this study should not be interpreted as a tool for predicting nerve injury. Its intended role is to structure radiological decision-making by identifying cases in which panoramic findings may justify three-dimensional anatomical clarification. Because postoperative neurosensory outcomes were not systematically available, this study cannot determine whether the proposed framework reduces the incidence of inferior alveolar nerve injury or changes surgical treatment decisions. Future prospective studies should include standardised neurosensory assessment, surgical decision-making outcomes, and external validation of the proposed framework.

Recent systematic evidence also supports the need to distinguish radiographic proximity from postoperative neurosensory outcomes, since imaging signs may improve anatomical assessment but do not necessarily translate into a direct prediction of IAN sensory disturbance in individual patients [24]. Additional clinical studies have similarly shown that panoramic and CBCT-derived parameters have limited standalone predictive value for postoperative neurosensory disturbance, although specific CBCT features such as canal compression and validated risk models may provide complementary information in selected high-risk cases [25–30].

The difference between the ROC-derived cutoff and the final selective referral framework should also be clarified. Although the presence of at least one panoramic sign maximised sensitivity according to Youden's index, this threshold showed limited specificity and would have resulted in a larger number of CBCT referrals. The final exploratory framework therefore prioritised clinical applicability and radiation justification by combining the strongest individual predictor, cortical interruption, with the presence of multiple panoramic risk signs. This decision was not intended to define a definitive diagnostic cutoff but to propose a more conservative referral approach requiring external validation.

The retrospective application of the selective CBCT framework identified 33 of 38 CBCT-confirmed root–IAC contacts (86.8%) while recommending CBCT in fewer than 40% of mandibular third molars. The framework showed high specificity and PPV in this retrospective sample, as no false-positive CBCT indications were observed. However, because the framework was derived and tested within the same dataset, these estimates may overestimate its true clinical performance. Therefore, the proposed framework should be considered a pragmatic referral framework requiring prospective external validation rather than a defini-

tive prediction rule. The five CBCT-confirmed contacts missed by the framework further highlight that the absence of cortical interruption or multiple panoramic signs does not completely exclude anatomical root–IAC contact. Therefore, the framework should not replace individualised clinical judgement, particularly in cases with difficult panoramic interpretation, unfavourable anatomy or high surgical complexity. These findings suggest that a rational use of CBCT based on the presence of panoramic risk signs, modulated by examiner experience and surgical complexity, may optimise the balance between radiological decision-making and radiation exposure. This framework is consistent with radiological justification and optimisation principles, according to which CBCT should be prescribed only when the expected diagnostic benefit cannot be obtained from conventional imaging and when the acquisition protocol is adapted to the clinical question [9,31,32]. In this regard, Sanmartí-García et al. [21] suggested that CBCT may be useful in selected high-risk cases, although current evidence does not support routine CBCT for all mandibular third molars. Recent evidence also supports a selective rather than indiscriminate use of cone-beam computed tomography in mandibular third molar surgery. Ruiz-Roca et al. [33] reported that the combination of root darkening and interruption of the cortical line on panoramic radiography increased the probability of IAC-related sensory alteration, while Robbins et al. [23] concluded that adding CBCT to panoramic imaging does not routinely reduce nerve injury rates when used indiscriminately.

Radiation optimisation should not be limited to the decision of whether CBCT is indicated but should also include the selection of an acquisition protocol adapted to the diagnostic task. When CBCT is considered necessary, field of view, voxel size, exposure parameters, and reconstruction settings should be selected to answer the specific clinical question while minimising radiation exposure. Recent evidence comparing low-dose, standard-dose, and high-definition CBCT protocols has shown that higher nominal resolution does not necessarily translate into superior three-dimensional reconstruction accuracy, supporting the use of lower-dose protocols when diagnostically adequate. Therefore, selective referral and acquisition protocol optimisation should be considered complementary components of radiation protection [34].

4.1. Strengths and Limitations

The main strengths of this study include the participation of examiners with different levels of clinical experience, the use of CBCT as the reference standard, an a priori sample size calculation, and the application of a clinically oriented selective CBCT referral framework. In addition, the analysis of interobserver agreement provides relevant information on the influence of examiner experience in the interpretation of panoramic radiographic signs.

Several limitations should be acknowledged. First, this was a retrospective single-centre study with a limited sample size, which may restrict the generalisability of the findings. Second, inclusion was limited to patients who already had both panoramic radiography and CBCT available, which may have enriched the sample with higher-risk cases and introduced selection bias. Therefore, the prevalence of root–IAC contact and predictive values should not be extrapolated to unselected third molar populations. Third, the selective CBCT referral framework was derived and tested within the same dataset, creating a risk of overfitting and optimistic estimates of sensitivity, specificity, PPV, and NPV. Fourth, although the analysis was performed at the tooth level, some patients contributed bilateral molars. Patient-level random-effects models were explored but showed convergence problems due to the structure and limited size of the dataset. Therefore, no formal adjustment for within-patient clustering was included in the reported models. This may have led to underestimated standard errors and potentially overestimated statistical significance; consequently, the regression results should be interpreted as exploratory.

Fifth, postoperative neurosensory outcomes were not systematically assessed. Therefore, the study cannot determine whether panoramic signs, CBCT-confirmed root–IAC contact, or the proposed referral framework predict or reduce postoperative inferior alveolar nerve sensory disturbance.

Sixth, interobserver reliability for CBCT measurements was moderate for some anatomical parameters and poor for the transverse canal dimension. This variability should be considered when interpreting CBCT-derived measurements and supports the need for standardised measurement protocols and further reproducibility studies.

4.2. Clinical Implications

Panoramic radiography remains an appropriate first-line imaging modality for mandibular third molar assessment. However, when cortical interruption or multiple panoramic risk signs are present, CBCT may be considered to clarify the three-dimensional root–IAC relationship and assist surgical planning. In cases with a single non-cortical sign, referral should be individualised according to surgical complexity, image quality, examiner experience, and medico-legal considerations. This framework should not be interpreted as a validated prediction rule for postoperative IAN injury but as an exploratory aid for radiological decision-making requiring prospective external validation.

5. Conclusion

Cortical interruption was the panoramic sign most consistently associated with CBCT-confirmed root–IAC contact. However, interobserver agreement was limited, and root–IAC contact should not be interpreted as equivalent to postoperative IAN injury. The proposed selective CBCT referral framework may help structure CBCT referral decision-making, but its diagnostic performance was estimated retrospectively within the same dataset and may be optimistic. Prospective studies with external validation, adjustment for patient-level clustering, and standardised neurosensory outcomes are required before clinical implementation.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/dj14120762/s1, Figure S1: Distribution of panoramic radiographic signs; Figure S2: Association between root position relative to the IAC and panoramic radiographic signs.

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Data Availability Statement: The anonymised dataset underlying all figures and statistical analyses reported in this study, together with the R code used for data analysis, will be made available in an anonymised repository upon acceptance.

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superior cortical outline of the mandibular canal, canal narrowing or darkening, root deflection or narrowing, island-shaped root apex, and the presence of multiple radiographic risk signs; and (2) CBCT assessment to evaluate the anatomical relationship between mandibular third molar roots and the inferior alveolar canal. Include representative panoramic and CBCT images, a dental imaging device, and directional arrows connecting the stages. Emphasize the importance of selective CBCT use to reduce unnecessary examinations." The authors reviewed and edited all AI-assisted output and take full responsibility for the final content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

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